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"DIE BAUTECHNIK"

12. Jahrgang Heft 26

II. Enlarged Quarter (of the year) Book 1934

By
Dr. Ing. Fritz Orth Berlin

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THE ALLUVIAL DEPOSIT IN DAMMING RESERVOIRS

1. Generalities

The constructions of large damming reservoirs on a greater scale has been approached only in the last decades. Most of the dams are scarcely older than 30 years. This is the reason for the lack of data on the rather disagreeable fact of alluvial sedimentation particular at streams carrying heavy bedload where the effects become perceptible only after a long period of time. The known information of such investigations are for the greater part even worse. The author has collected the results of known experiments and discussed their merits with the purpose of showing how to consider the alluvial deposit in a practical way at design and construction of dams.

We now deal with the diminutives of the storing volumes only--not with discharge or the clearing of the service water (of sand). For the sake of better explanation some smaller dams without storing reservoirs will be mentioned.

2. Process of Alluvial Sedimentation

Every stream carries solid particles which either are rolling or jumping along the bottom or are suspended and distributed all over the cross-section of the stream and transported by the flow. The first kind is called bedload the second sediment or deposit both are signified as heavy bedload. There is no exact limitation between bedload and sediment because both are influenced by changed flow or water volume. The transport of heavy bedload at high water partly reaches extremely great values whereas at low water often practically it goes back to naught. Allone of sediment as highest values in g/l were measured at:

Ache in Tyrol	1.5
Aare	2.7
Reuss	2.6
Lech to	4.2
Diverse streams at melting snow to	30. and more

Mostly only the deposited sediment is measured because the determination of its volume is less difficult and because it represents the far greater portion of the whole (heavy) bedload transport. Published data gives very varying statements about the proportion. The Americans calculate with a value of 80% (sinkstoffe) deposited sediment and 20% of bedload (suspended) (Rio Grande) only 1% bedload was found in the Mississippi and on the Wolga (Russia) even only 0.2 to 0.08%.[2]

The sedimentations also play an important mostly underestimated part at the upper sections of mountain streams for instance Muhlhofer at his investigations at the Inn near Kirchdichl found that 2/3 of the transported heavy material was sinkstoffe.

The determination of the deposited sediment may allow a raw calculation of the general bedload freight but it is not of great interest otherwise in regard to sedimentations questions whether bedload particles reach the basin suspended or rolling on the bottom because more and more suspended particles are depositing themselves at the decreasing velocity in the basin. This points to the greater significance of the sieve curve of the complete heavy sediment.

Here it shall be tried to explain the small proportion of bedload at the heavy bedload transport in general measured in great streams.

The sieve curve of heavy bedload in a channel downstream shows always a finer size of particles. If now the limit (at the middle of the year) between bedload and deposit (of uniform particles) remains the same at the lower section of the stream as that of the upper section then the bedload proportion downstream must strongly decrease. The critical size of particles of course is also finer but not of a corresponding measure to the greater fineness of heavy bedload. The explanation of the measured small participation of bedload in the lower sections of great streams seems to uphold the fact of decrease of heavy bedload freight from source to estuary. The process of sedimentation in the reservoir starts at the inlet (entrance) and spreads in delta formation slowly towards the dam. But the bedload (deposit) are distributed all over the length of the reservoir; the particle size becomes finer and finer towards the dam. The greater the length of the reservoir with simultaneous in and outflow the greater the fact of sedimentation of even the finest particles. Reservoirs partly filled and for a long period without any discharge of course show a complete (thorough) sedimentation.

So for instance at the Elephant Butte Dam--72 km of length where the sedimentation also of the greatest portion of bedload took place at the upper kilometer whereas the deposit further towards the dam consisted of finest mud and became almost naught. Such would not have been the case in a shorter basin.

Any reservoir (basin) after the elapse of more or less time will show a complete sedimentation if it is not regulated by especial means. But the periods of time during which a complete sedimentation would fill up the basin at any dam construction are at least at most German dams extremely long and for this reason excluded from our advancing reflorious. But at many other dams with strong and heavy bedload transport these periods are rather short as demonstrated by table 1 where a number of instances are collected whose closer investigatéons brings to our

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might the grave significance of this problem. We especially point to the completely silted basins of [illegible] and others.

The chosen designations at the head of the table respective in the text are:

Sedimentation per year = MV (M³/ year)

Sedimentation per year and km of area subject to rainfall
= specified sedimentation = MV = MV/F
(M³/ year and km²)

Sedimentation as portion of basin volume in 0/0 = grade of
sedimentation = g = V/I [illegible] basin volume as multiple of
middle yearly sedimentation in years = duration = [illegible] =
I/MV (years) volume of basin in relation to area subject
to rainfall height of damming (level) = S = $\frac{I/F}{1000}$ (mm)

proportion of heavy bedload deposit = a = V/G
heavy bedload freight per year = G (m³/ year)
heavy bedload freight per year and km = specified heavy
bedload freight = g (m³/ year and km²)

Figure 1 illustrates the rather growing progress of sedimentation of the [illegible], fig. 2 and 3 show similar deposits in the [illegible] Lake (Austria) and of the [illegible] in Silesia.

The influenced river channel (slope of bottom) above the inlet of the basin and the influence of the basin upon the river bottom below the dam (wall) are additional phenomena of the sedimentation process and dealt with in the original work. Here we neglect that dissertation for the reason of lack of printing space.

EFFECT OF SEDIMENTATION AND THE RELATED INFLUENCE OF THE AREA SUBJECT TO RAINFALL

1. Generalities

In the following it shall be tried to determine the influence of the area subject to rainfall upon the magnitude of the sedimentation (deposit). An investigation of the influence of the reservoir basin will be made in another chapter.

In order to exclude the influence of the basin we have to assume it of indefinite measure and that all the heavy bedload is deposited in it.

In this case the ratio of sedimentation at the middle of the year is equal to that of the bedload freight.

The heavy bedload freight at a certain given point of the stream is influenced by the formation condition of the area subject to rainfall proper and by the capacity of the stream to transport heavy bedload at the section above the observation point. The many related problems for the greater part unsolved will here only shortly be touched.

2. The Formation of Heavy Bedload in the Area Subject to Rainfall.

The formation of heavy bedload depends on many circumstances and only some of the more important will be mentioned. (fig. 4)

a. Topographical condition. It is obvious that the formation of heavy bedload is far stronger in an area of steep slopes than in a plane so for instance are the condition at the Alps very different from such at the German intermediate chain of mountains. Extremely heavy bedload transport are often causing [illegible] protected small canals from mining establishments. The heavy sedimentation of the [illegible] reservoir at the [illegible] is caused by it. The almost 15 [illegible] thick deposits of mud are so substantially mixed with coal that the management considers the retrieval of the coal by using a dredger.

b. Precipitation and discharge. Here besides the magnitude of the precipitation respective of the discharge it is the distribution of both which influences particular the magnitude of heavy bed load formation.

c. Influence of the soil nature. It may be pointed out that alluvial soil causes a greater specific heavy bedload transport in the discharge area [illegible] and sediments of all sorts cause a greater bedload transport than primitive gneiss.

d. Influence of forests on agricultural soil. The formation of heavy bedload in a wooded area declines down almost to naught, whereas agricultural soil particular on slopes contributes great volumes.

e. Influence of soil moisture. It has been found that dry soil shows less resistance than moist soil and it is known that at the same area subject to rainfall the second flood (high water wave) mostly transports less heavy bedload than the first one. This shows clearly why dams in arid areas like such as in Algiers or Texas have their difficulties by the voluminous deposits of bedload.

3. Transport of Heavy Bedload in Stream Channels.

The stream channel of course is the conveyance for the transport of the heavy bedload which has been formed in the precipitation area proper. During the process of transport some portions of the bedload is lost and other portions [illegible] on the bottom are

carried along. Other losses are effected by the flow through a lake or over raised sections. Now and additional bedload is deposited at sections of the channel which have been deepened which particular can be the case after the transmitting through a lake and with periodical periods.

Whereas so far we dealt with the diverse influences of the precipitation area proper and the way and means of heavy bedload transport we will here mention that the so influenced freight at a certain point in turn influences the formation of the stream bottom in its profiles of length and cross sections. By considering the meager data about heavy bedload transport we may only intimate that at equalized stream length profiles particular the fall at a fixed observed point reflects the whole upper mentioned influences. But this is correct only at equalized longitudinal profiles that means if the flow conditions are such as the stream at every point of the longitudinal profile is capable to carry the heavy bedload from the precipitation deposited at just this point farther away so that within a period of time neither a raising or declination of the bottom occurs. In such a case it would be possible to obtain a conclusion of bedload freight by an examination of the fall conditions.

But if heavy bedload deposit alternates with sections of heavy deposit then the freight at a small fall at the begin of a deposit section can be much greater than at about the begin of a faulty heavy bedload section (here heavy bedload freight caused by declination of the bottom is carried at a far greater fall while all other conditions are equal). Capacity of transport should never be mistaken for real transport.

4. Definition of Influences.

Naturally it would be of great importance if the influences of the sedimentation problems at man made stream regulations and the sufficient correct coefficients of heavy bedload freight could be determined. Our knowledge about heavy bedload transport so far is still very deficient. Many attempts were made to establish formulas for calculations but the foundation of this empirical formulas proved to be deficient so that the formulas mostly do not cover the complete heavy bedload freight but only the transport of detritus.

In the known formulas of bedload freight (not heavy bedload) at a fixed point of a stream channel appears particularly the fall at this point as an essential factor. The best known of these formulas are:

Schoklitsch : $G = [illegible]$
Kreuter : $G = x_1 A J^{[illegible]}$
Wilhelm : $G = x_2 Q_m J$

Q signifies flow of water per second.
Q_0 " volume of water at start of bedload motion.
J " mean fall at the respective location.
A " yearly discharge in m^3.
Q_m " mean volume of discharge in m^3/ sec.
$x_1 x_2$ corresponding coefficients.
G " bedload freight.

As already mentioned the consideration of J possesses a value only at an equalized longitude profile of the stream current. The two last formulas are comprising only the magnitude but falsely not the distribution of discharge which is the far better expressed by the formula of Schoklitsch. The final conclusion from this consideration is that before we can derive useful relations between these upper sediment [illegible] and the heavy "bedload freight" we still need dependable results of experimental measures and tests. The definition of heavy bedload freight still rests at the first beginning. A complete investigation of it in a stream channel from source to estuary so far is not available in the various reports. The production of useful instruments for this purpose was approached only very recently.

So far we dealt always with heavy bedload freight that means "the quantity."

Later we will report about the connections between the condition of the precipitation area and the characteristics of the heavy bedload [material] and of the influence of the magnitude of sedimentation which consequently takes place.

THE EXTENT OF SEDIMENTATION AND THE CONDITIONING INFLUENCES OF THE RESERVOIR

After contemplating the heavy bedloads freight which is identical with the sedimentation or deposit in a reservoir or basin of indefinite measure we now shall investigate how much of it is deposited in a basin in regard to its measure location formation and particular sort of management.

1. Size of the Reservoir.

The portion a of the heavy bedload freight which deposits itself increases with the relative size of the reservoir which in table 1 has been computed by the storing height h for [illegible] reservoirs (fig. [illegible]). One could have determined the relative size also by the proportion between mean volume of yearly discharge and volume of reservoir but this was not used for a basis of further considerations for the simple reason because these data could not have been ascertained at most of the instances. As an illustration of size differences let me mention only the following instances: the [illegible] dam can be filled by the mean yearly discharge [illegible] times but the [illegible] only [illegible] times. Whereas at one of

then some kind of discharge of water goes on almost permanently there is a t the other lay sometimes for months no water discharge whatsoever which of course causes the deposit of any sort of heavy bedload.

Whereas the transported bedload of more substantial size almost always comes to deposition it is the sediment of which only a portion remains in the reservoir.

In order to define the quantities the calculation has to be based on a sieve curve of sediment with the help of the fall velocities of the individual particles in water and the mean flow velocities of a flood flow. Of course such a calculation neglects the turbulence and also the flow velocities which under circumstances a t great cross sections are of a very uneven distribution. In the following we recapitulate some instances of the magnitude of the value a in dependence to the storing height s.

The specific sedimentation in the Austin dam on the Colorado (Fig. 6) is reported according to table 1 with [illegible] m³/km² and with an eventual drop to [illegible] m³ and even lower whereas the heavy bedload freight of the Colorado according to more recent measurements in average is [illegible] m³/km² which corresponds to the [illegible]%. a fluctuated between 0.62 and 0.40. At further increasing sedimentation (s = 0.020 and s = 0.005 km) [illegible] dropped to [illegible] respective [illegible] m³/km² which corresponds with a. a of [illegible] respective [illegible].

The following values a according to Collet were measured in the small reservoir Kallnach on the Aare:

1914 : 180 m³/km²	1917 : 130 m³/km²	middle 1914-19
1915 : [illegible] m³/km²	1918 : [illegible] m³/km²	
1916 : 130 m³/km²	1919 : 94 m³/km²	135 m³/km²

In 1919 according to Collet measurements of sediment on the [illegible] (including a substantial portion of the precipitation area of Kallnach) were performed which after conversion to sedimentation space resulted in 206 m³/km².

According to an estimation of Collet contain the 94 m³ etc. 34 m³ former sediment and 60 m³ bedload so that one can say that 1919 of [illegible] = 206 - 60 = [illegible] m³ only = 34 m³ that is a = [illegible]% came to deposition ([illegible] = 1.33 km).

The small storing reservoir Kallnach is situated directly above the junctions of the Aare with the Bieler lake. The delta measurements in the lake at that previous to the completion of the Kallnach reservoir obtained about uniform quantities as such at Kallnach so that ______ an in this case of delta measure = 35 to 40% of the heavy bedload freight are ascertained.

At the [illegible] reservoir in 1908 it was found that [illegible] m³ heavy bedload deposited 97,700 m³ (a = [illegible]) and in [illegible] [illegible] m³ heavy bedload deposited [illegible] m³ (a = [illegible]). There a at its start was [illegible] m later correspondingly less.

At [illegible] the observed heavy bedload transport was [illegible] m³/km² whereas it was only [illegible] m³/km² so that here is a = 7.1 %.

The portion of sedimentation a a reached 100% the more the fewer sedimentation traces are met before the dam wall. So the deposits in the [illegible] reservoir of [illegible] in Silesia are at the upper part is [illegible] m high and decrease towards the middle to a scarcely visible height to vanish completely before the wall.

But at the dam of [illegible] on the Bober it is to assume that in spite of the great a = 41.8 m, at least before the building of the upper reservoirs a substantial portion of heavy bedload left the reservoir because there are still deposits up to [illegible] m thickness before the wall. The upper lately built smaller dams of Boberrohrsdorf and Boberullersdorf have much smaller a.

Assuming that (see table I) that [illegible] = [illegible] m³ indicates about [illegible] of the heavy bedload freight of the stream (instead of F = 1200 km²) there is for Boberrohrsdorf:

$$G = \frac{[illegible]}{[illegible]} \cdot \frac{1}{[illegible]} \cdot [illegible] = [illegible] \text{ m}^3, \; [illegible]$$

is then for this reservoir $a = \frac{14,700}{[illegible]} \cdot 100 = [illegible]$

which close conform with the upper mentioned values.

As expected we find with growing J an increase of the sedimentation portion of the general heavy bedload freight.

Of course form of reservoir sort of management and particle size distribution of the heavy bedload are included in the values. The greater the [illegible] of sedimentation particular in a reservoir of smaller [illegible] height the smaller is the share of the quantities coming to sedimentation. (see chapter [illegible]). A [illegible] also of later enlargements of the dam by [illegible] its wall. Observe in table 1 the increase of V from 1.5 km³ to [illegible] km³ by [illegible].

The increased sedimentation observed during the last decade is effected by a gravel trap at an upper section formed by a forest of tamarisk.

2. Formation of the Reservoir.

At very large B the formation is of no influence on the size whatsoever. But at small reservoirs where relative great quantities of sediment are discharged with the flow for the bedload deposits in reservoirs of uniform size by equal conditions are not influenced by the formation but the quantity of transported sediment is influenced if only little because the horizontal way traveled by the suspended bedload reaching the wall is shorter but so is the horizontal velocity smaller whereas in oblong but less deep reservoirs the way traveled by suspended bedload particles towards the wall is longer but the horizontal velocity is also greater. The conditions of course are not easily conceived because the deposition of sediment is delayed by the turbulence of the water.

The fact that the specific heavier river water loaded with sediment is shifting itself at the inlet beneath the clearer water of the reservoir produces a smaller depth of fall but creates at the same a increased horizontal velocity of the small bedload particles.

At a comparison of short broad reservoirs with oblong narrow ones one has to watch that at the first an reduced velocity of flow corresponding to that short way exists because it is assumed that the water only in a stream from inlet to the storing wall is showing a streamer motion whereas the side water takes little or no part in the motion. But the formation of the reservoir is of much greater significance to the flushing (chapter VI).

3. The Location of the Reservoir on the Stream.

The proportion z of the sedimentation of course depends particular on the various geographical and other conditions which influence the bedload and form its proportion e.g. combination of particles their size formation (whether edged or rounded) their weight a.s.o.

So it became a fact that at two reservoirs of uniform storing height and equal quantities of supplied bedload the one on the upper stream section located reservoir was more exposed to deposits than the lower reservoir because the heavy bedload is of finer particles downwards and more bedload at the wall can be carried away. It is regrettable to have not enough experimental data to compare this influence by facts.

Here a interesting observation at storing weirs in South Africa may be mentioned that salts of the water cause the precipitation of the suspended fine bedload if the water is not used for a long time and the percentage of salt increases substantially at strong evaporation therefore where a flow has to be provided it only a weak whirling and this can best be effected by low lying discharges.

4. Operation of the Reservoir.

The proportion of the heavy bedload freight coming to sedimentation is also authoritatively determined by the operation of the storing reservoir whereby such regulations for the discharge of water from the reservoir are meant as they are stipulated in the water exploitation plan not necessarily aiming at the flushing (as will be later spoken of in particular in Chapter II) which by the kind of operation completely hinders the depositing of a portion of the heavy bedload or brings already deposited quantities again in motion. This are: the high water (flood water) discharge by overfalls (weirs) respective the low lying discharges and the withdrawal of water.

The sedimentation portion of heavy bedload is the stronger the more complete. The equalized water conduit is (which is formed by the [illegible] between the high water volume with their great quantities of heavy bedload are completely trapped because the equalized discharge contains only small volumes of sediment.

The more the discharge curve branches away from the almost straight form and follows the high water points or the steeply the smaller is the portion of sedimentation. It is also of importance in which way the high water discharge is effected whether by an overfall which of course sometimes carries substantial volumes of sediment (if the thickness of jet is strong enough) or by low lying discharges which if of sufficient measure are always of greater efficiency than over falls or whether the whole original cross section of the stream can be made free for high water discharge by adjustable weir.

COURSE OF SEDIMENTATION AND DURABILITY

1. Decrease of Sedimentation ratio by Growing Deposit in the Reservoir.

The questions of sedimentation ratio and durability of a reservoir are of foremost interest to any hydraulic engineer that means he wants to know what portion or volume of his storing reservoir will be lost to him in a year and how many years it will take to render his reservoir practically useless.

According to the example we have [illegible] the value a constantly at an individual reservoir with increasing deposit and correspondingly decreasing a until it drops to nought if the state of inertia is reached. Therefore at laying out the summary curve of the sedimented damming room we obtain a curve whose steep initial segments have a increasing flat course until the curve approaches a symptotical the horizontal at the height of the capacity of inertia (Fig. 6).

The capacity of inertia that corresponds to a final state of inertia at which no sedimentation takes place for longer periods of time.

The capacity of inertia of course depends on the proportion of the heavy bedload and of the reservoir but foremost on the operation of the reservoir. If for instance one imagined the for many reasons practical impossible condition of storing up only an absolute pure inflow and discharging any supply (transporting heavy bedload) without any damming (perhaps by taking every time the whole weir away) then the capacity of inertia would be like the original. The more often the reservoir is empty and the less dammed the supply flows through the discharges of sufficient measure the greater will be the capacity of inertia. The capacity of inertia (aside other points) also forms a the greater part of the original capacity as the storing height s is smaller. Generally the mostly rather irregular course of the sedimentation summary curve can for practical purposes be substituted by a theoretical curve with the equation:

$I'_n = I' a^n$ .... (1) because a single (high water) flood can cause a stronger increase (growth) than the supply of several years in more equal [illegible] periods.

In this equation I'_n signifies storing space (volume) not subjected to sedimentation after n years as portion of the room $I' = I - I_{tot}$, [illegible] contents by which the reservoir becomes practically useless and is abandoned a = coefficient of sedimentation grade n = number of years since start of operation up to the time of observation.

The sedimentation in the n th year according to this equation is:

.................................(2)

Because always a 1 is, V_n decreases.

The proportion of sedimentation x of the heavy bedload freight in the nth year is:

.................................(3)

The sedimentation grade g_n in the nth year is also decreasing correspondingly.

.................................(4)

2. Durability.

The durability is to be computed from equation (1) $I'_{n_d} = r I' a^n$ to

.................................(5)

r is given by the operative conditions. a = at the design of a reservoir is either to be estimated from similar instances or to be computed according to an observation of n years from equation (1).

.................................(6)

The author has computed as values of a at:

Austin .... a = 0.73
[illegible] .... a = 0.92
Lake Penick .... a = 0.948
Lake Worth .... a = 0.973
Keokuk .... a = 0.989

Short durabilities signify small values a and great durabilities signify great values a.

The upper mentioned calculation methods are to be looked upon only as first experimental tests. We still do not have enough experimental data to stipulate generalizations.

At very large reservoirs a will remain constant = 1.0 for a long period. First it decreases correspondingly if quantities of sediment go over the weir are discharged by the outlet at the bottom. Artificial interferences as flushing and other means which are highly effectful at the same rate as the sedimentation has progressed were neglected. The durability calculation in table 1 represents only a quotient of the whole content of reservoir I and the mean yearly sedimentation of the available experimental results. The durability on one hand is given as is short because no later progressing decrease of a had been considered and it had been overlooked that a portion of the sedimentation volume deposits above the damming pool and so does not diminish the original storing space (see fig. 1) but that for a part is represented by the face of writing I instead of rI'.

Following are some instances of complete sedimentation of room I' and of reaching a certain state of equilibrium:

At the earlier mentioned dam Austin lake now is only a relative small room (space) stretching along the length of the reservoir which is not sedimented.

At the weir of Chevres on the Rhone which completely became sedimented (except of a flow bed) after ten years of operation now not only the sand but the gravel also is transported like formerly in the channel of the Rhone preparing the same fate for the lower situated dam of Chancy Pougny.

Mostly it will happen that a far progressed but not definite state of sedimentation appears another condition of equilibrium for sections of bedload deposits at the inlet as for the deposit sections further towards the weir. So it was assumed that at the dam of [illegible] on the [illegible] the inertia flow types sections of the first would be = 300 m² and of the second = 500 m².

Viewed in geological periods of time a natural or artificial lake signifies only a short termed disturbance of the state of equilibrium of the stream which is eliminated by deposits. Collet says "The history of a lake is the history of its death." Even natural lakes disappear in remarkable short periods of time. So Krebs[11] mentioned a chart of Tyrol from 1774 which contains more than hundreds of lakes not existing since. Accordingly to him are all those names of towns and counties like Seeboden Seealp Seeberg Seewiese pointing to former lakes at their situations.

Particular such basins passes through by great streams (small s) disappeared first (Rosenheimer and Salzburger See) whereas the greater lakes still existing have only small contributaries. (Worther See Achensee Zellersee Ossiacher See and others.)

The delta of the Rhone in the lake of Geneva since the old Roman time has advanced for about 3 km for that is the present distance of the port Valais (formerly the harbour city of Valesia) from the lake. At a progress of the same ratio the lake will be filled up by deposits in = 45,000 years and then form an alluvial lowland.

Lucky enough most of the dams do not suffer a substantial decrease of their capacity within the usual periods of deduction. Therefore a complete sedimentation occurring much later does not mean a loss of the invested money. But it may mean the loss of a desirable dam site for the future generations and that is certainly of great importance. This very question is of particular significance regarding irrigation dams in arid areas where as already stated an especially strong sedimentation exists and so in due time cause the elimination of artificial irrigation just by the failure of water storage and so turning back an once prosperous agricultural land into waste land.

In the following will be shown what resources are obtainable to stem the progress of sedimentation in difficult instances.

PRECAUTIONS AT WATER RESERVOIRS AGAINST SEDIMENTATION

1. Generalities

The method of precaution can be divided into three large groups of which the first one should hinder or lessen the entrance of heavy bedload into the reservoir: the construction or precipitation area and protecting dam.

The second group effects a protection by dredging the deposits or flushing such.

flume is controlled [illegible] f the state of equilibrium [illegible] ts. Collet says "The history [illegible] tural lakes disappear [illegible] s' mentioned a chart of [illegible] ds of lakes not exist- [illegible].

[illegible] basins passes through great streams (small s) [illegible] (Rosenheimer and Salzburger See) whereas the greater [illegible] have only small contributaries. (Wörther See [illegible] aiacher See and others.)

The delta of the Rhone in the lake of Geneva since the old Roman time has advanced for about 2 km for that is the present distance of the port Villeneuve (formerly the harbour city of Valesia) from the lake. [illegible].

[illegible] ing much later does not mean a loss of the [illegible] may mean the loss of a desirable dam site for [illegible] of great importance, [illegible].

[illegible].

PRECAUTIONS AT WATER RESERVOIRS AGAINST SEDIMENTATION

1. [illegible]

[illegible] be divided into three large groups of w [illegible] and lessen the entrance of heavy bedload [illegible] construction or precipitation area and pro- [illegible].

[illegible].

The third group consists of consideration of the disturbing deposits in the design by providing an effectful sedimentation space (or room) or by a weir.

2. Obstruction in the Area of Precipitation.

A very good method particularly at dams in high mountain regions is that which is used for the diminishing of the process of formation of heavy bedload in natural streams at areas subject to erosion.

But this method to increase the period of usefulness of a reservoir proves to be a very expensive one because it requires an area of immense expansion for the erection of the obstructions.

But a complete stop to the forming of heavy bedload in the area subject to erosion can never be accomplished and furthermore would not even be advisable because it would disturb the equilibrium of the stream. The stream at any changes of transported bedload volume would react with corresponding changes in the course of transport velocity and condition of the cross sections.

An operative reduction of the heavy bedload transport above signifies to a decisive point of the mean course of a stream the same thing than a levelling below this point namely a deepening of the bottom. If the present bed of a stream (as often is the case) for great distances rests upon a diluvial bottom filled by gravel then the obstruction of the bedload formatives in the area of erosion beneath a fixed limit would not mean a reduction of heavy bedload transport at the mean flow because the stream for the endurance of geological periods can take heavy bedload from this store.

The consideration and building of such improvements in a determined area mostly demands many years particular if the finished construction should not prove to be of sufficient effect then it may take decades of years to perfect the dam.

In an accompanying calculation of the reforestation of the area (subject to rainfall) of a storing dam (southwest of U.S.A.[10]) has been found that the reservoir 40 years after completion will show not 3/4 but only 1/4 of its space taken up by deposits. In addition to this agreeable fact comes the value of the forest.

The delta of the Po during the later centuries showed a three times faster progress than during the medieval period the cause of which is pointed out by the deforestation of the area subject to rainfall.[11] Whereas the construction of the approach for a great part consists of a fall reducing effect. The increase of fall above a dam indicates an enormous increase of deposit

The diversity of the measured deposits in the [illegible] lake (see table 1) has its cause in the extensive reserve reduction of the lake which began in [illegible] and whose effects may gradually die.

3. Protective Dam.

a. Protective dam with by pass channel. The fundamental idea of this construction is to catch the heavy bedload at the approach to the inlet of the reservoir in order to conduct it by the way of a by pass again back in to the stream. A small dam construction is erected mostly any way necessary during the building period as a trap dam from where then the greater portion of floodwaters transporting heavy bedload is conducted through the by pass channel whereas only the clear water falling over the weir reaches the general reservoir. Gallery or channel may serve as by pass. Both sorts were used. Constructions having galleries are at: Amsteg [illegible], channels: [illegible]. Channel and gallery: [illegible].

A proposal to use a large iron concrete tube for a by pass through the reservoir has not been realized for reasons of high expenses.[13] Such a storing dam with by pass channel is suited for reservoirs of power plants only which have small storing height (level) and are of small length. So for instance was the important weekly dam Amsteg[13] (Fig. 7) particular endangered because of its small [illegible] (=the mean yearly heavy bedload freight = 100,000 m³ is half as large than the capacity of the dam—) and had particular be protected. The necessary by pass gallery measured only 382 m of length.

The by pass must have the capacity to take care of the greater portion of floodwater because it is exactly this floodwater which should not enter the reservoir. At Amsteg is the HHW. 350 m³/sec of which the gallery absorbs 325 m³/sec. The by pass has always to be of substantial measure and is only possible by great masses of water which is mostly corresponding with the upper mentioned small storing height. These small and very short reservoirs with the great excess of water are also mostly those at which flushing shows good results so that in individual cases it should thoroughly be considered whether such a reservoir should be perfected by an expensive by pass or if the flushing method should be preferred. The at dam construction always necessary by pass does not need to be constructed for such great flood water volumes and does not need such a careful construction as in our case had to be provided in regard to the disturbing effect of the shearing force.

Instead to construct by passes one could think of taking the reservoirs fully from the stream valley and construct it upon the table-land sideward or upon old valley bottoms. But that would at best result in too small storing volume of water.

b. Protective dam without by pass. The protective dam without a by pass channel catches the heavy bedload at a dangerous rate and in consequence of the small [illegible] only during a definite short period and then loses its whole value. The general advice therefore is to abstain from construction of such dams and instead of it provide storing room by a moderate heightening of the wall of the reservoir.

But if the deposits of [illegible] behind [illegible] can be [illegible] out and placed to other useful purposes or if it can be transported without greater expenses and difficulties then the situation of course is different and one has here an exceptional well prepared material stored in a not too deep and too large place. But this propositions are most not economically warranted so that in general such a protective dam appears to be needless.

Different again are the conditions at preliminary reservoirs of retaining water from [illegible] purposes than is the clearing of the water besides protection against sedimentation.

In this connection we shall mention the dams of the surrounding area of [illegible] which [illegible] of their small capacity are looked upon as first [illegible] during the construction period in the area of erosion. Although no enduring protection by this dams had been expected their [illegible] in the [illegible] were so [illegible] short that by sufficient [illegible] the construction in that manner would not have been undertaken (see table 1 Aviso Luschari [illegible]).

H

a. Consideration of Effectiveness of Flushing Outlets.

By flushing we mean the removal of deposited sediment by the help of a waterflow which carries away the material mostly through an opening in the wall. Earlier it has been said that any plant operating discharging water from the reservoir at the same time would show a more or less effective but usually very small flushing.

Here is a report about the character of flushings by mean of a discussion of the factors favoring its efficiency.

Flushings are the more efficient:

1. the smaller the storing height at flushing
2. the greater the flushing stream at disposal
3. the greater the flushing outlet (discharge)
4. the lower the adjustment of the outlet
5. the more favorable the location of outlet
6. the greater the endurance of flushing
7. the narrower the reservoir (steep banks)
8. the greater the former fall of flow in the reservoir
9. the shorter the reservoir
10. the more straight the reservoir
11. the further the progress of deposits
12. the finer the particles of the sedimentation
14. the [illegible] the sediment of deposit is
13. the rounder the individual particle of sediment.

1. Storing height

First of all is pointed out that the flushing by the way of any outlet can be of full efficiency only at an empty reservoir.

The efficiency at restricted opening is limited to the closest vicinity of the outlet because the discharge corresponding to the present rate of pressure is covered by the supplying flow from all parts of the reservoir particularly also from the upper vicinity; the mean velocity of supplying flow is greatly increased except at the closest vicinity of the outlet.

This velocity already at small distance is not strong enough to bring and sand or particles of gravel into motion (see also tests of [illegible]. [illegible])

It is different if the discharge of the stored water is a complete one then a very deep channel is eating its way after short time streams up. The rapid growing of this channel has its cause in the fact that at the point up to which the channel just reached a steep talus slope reaches up to the critical height of the deposit over which the water plunges; flushing at empty reservoir signifies interruption of operation.

It is possible to interrupt the operation if at dams for power generation represents a part of a complete economy of supplies further if the storing height is not too great so that the refilling does not take too much time.

B. Magnitude of Flushing Stream.

In view of the former handled statements we will in the following know that by flushing is assumed a flushing of the empty reservoir is meant. It is clear that in general the effect increases with the magnitude of the flushing stream. The flushing causes great losses of water which makes particularly the economy of this method at irrigation dams questionable and at dams of power plants with great by passes also.

C. The Size of the Flushing Outlet.

The size of this outlet must show the right proportion to the magnitude of the flushing stream. At flood measures it was to be observed that with increasing volume of flushing water a gradual effect of the distance of opening reduces the flushing performance. The size of such outlets for the discharge of flushing water has to be proportional to its volume or vice versa.

Because of the limitation in measures at the construction of outlets and difficulties particularly if they are also used as an outlet at the bottom at substantial storage heights an especial flood (high) water is there used for flushing but only proportional volume of water.

Here follow some statements in regard to successful flushings at the Spanish dam of [illegible] which had been flushed through three outlets of together 14 m² cross section with water volumes from 2.9 to 7.7 m³/ sec. whereas the [illegible] 1000 m³/sec and [illegible] = 3.17 m³/sec.

Greater volumes of flushing water are needed for greater reservoir behind proportional low dams in lowland areas where the fall is low.

[illegible]

[illegible]

[illegible]

[illegible]

4. [illegible]

[illegible]

5. [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Other reason also will make a more or less dispense of flushing necessary at HW as that the several adjustable outlets allow the discharge of great HW by extremely low damming. The movable parts of modern weirs give such clear width that the few small piers do not obstruct the HW to a stronger degree than the piers of a bridge.

Particular great care had to be observed at the building of the dams on the highly bedload transporting Nile. The old masters of dam construction in Egypt (Willcocks[11]) with right pointed out that every dam obstructing the HW in their unhindered course to a higher degree will consequently show great sedimentation and deposits. It was for this reason that the dam of Assuan had not been built at an especially narrow location as usually is done to provide sufficient space for outlets in the wall. There is no overfall for HW. The wall has 140 outlets at the bottom each of 14 m^2 and 40 laying somewhat higher of 7 m^2 space together f = [illegible] m^2.

At HW = 10,000 m^3/sec is by through flow v = $\frac{10,000}{[illegible]}$ = 4.5 m/sec a velocity which can be produced by a damming of [illegible] 2 to 3 m. Only the proportional pure water of the White Nile is stored up; after expiration of the irrigation period appear the HW of the Blue Nile which is rich on heavy bedload but is not stored (August to October) and this waters carry away whatsoever of bedload may have been deposited so that according to newer investigations the sedimentation of the great reservoir is fully inconsiderable.

The following circumstances of course represent determining facts of the favorable flushing effects at Assuan: the long period of flushing (several months of not-used water flow) the small proportion of the reservoir the fine particle size of the deposits the ally early repetition of flushings e.s.o. (see also fig. 8).

4. Elevation of the Flushing Outlet.

The lower the elevation of the outlet the higher are the bedlay slopes at respective ratio of sedimentation and the better is the eroding effect of the flushing stream.

Of course attention has to be paid to the sluice which may under circumstances be packed by heavy bedload and that should be hindered by frequent attendance.

This at any rate has to be considered at the project because it lies in the low level (Tiefenlage).

5. Fundamental Plan Situation of the Flushing Outlet.

Some parts of a reservoir of peculiar importance (for instance before the approach construction) can be kept free of deposits by the respective

ic of

location of the projecting dams. The same medium can be chosen to give a particular direction of flow to the flushing stream at which greater volumes of sediment may be removed.

6. Endurance of flushing.

The flushing process of course requires a definite time for a complete effect. First a narrow channel progresses gradually stream up into which only by and by from the sides plunge quantities of mud.

If mostly after many days a certain state of equilibrium is showing itself by the fact that the channel neither becomes any wider than further flushing becomes needless. At the Spanish Irrigation Dams the flushing after the expiration of the irrigation period endured 28 days. Such a long time is not at disposal by storing reservoirs of power plants. There one is bound by the most effectful first days and the later flushing lasts not longer than for one week as is demonstrated in the following table:

Some results of flushings at Chevres on the Rhone[15]

Volume of water-flow through the reservoir m^3/sec	Hours of flushing	Total Volume of water hm^3	Removed material m^3	The same per hour m^3	Volume of 1 m^3 of removal m^3	Vol. % heavy bodied flush water %
400	10	14.4	78,000	7800	185	5.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Flushings of a few hours of course have only very little value. At the removal of greater quantities at the [illegible] had been accomplished only after a general repair during which the reservoir was kept empty for several weeks. [illegible][16] reported how a mud bank of 600 m length formed directly above the weir at the inner side of a curve expanding over half the stream width has been gradually removed. This mud bank appeared already on the first day at the water level. By elimination of the water cross section near this bank remained only the half of the stream towards the concave shore for the flow of the stream. The reduced cross section of the stream caused increased velocity of flow and a stronger attack upon the masses of mud. After the complete lowering of the water level the Aar brought on a HW which within two to three days removed all the mud masses. Surprisingly quick was the shifting of the slope edge on the waterside of the mud dune towards the shore. At the broadest point on a single day [illegible] m were carried off. At this location alone the removed quantities of mud were estimated at round 4[illegible]0,000 m^3.

7. Width of the Reservoir.

Now we will shortly deal with the properties of the reservoir which comprise a decisive influence upon the flushing. We understand that the flushing effect is the stronger the greater the share of the channel width (scoured by the flushing stream) from the entire width is. At a small reservoir with steep slopes great portions of the masses on the sides will slide into the channel and carried away by the flow. The character and quality of this masses naturally is of significance in the sense of such landsliding, fineness of ground grade of moisture and [illegible].

Of particular influence is also:

8. The Necessary Fall of Flow in the Reservoir.

9. The Length of the Reservoir.

10. The Form of Ground Plane of the Reservoir.

It is with lucky coincidences of such circumstances (short steep straight reservoirs) which at a number of well known dams in Spain: Pantano Alicante (Tibi) a.s., through centuries in spite of substantial heavy bedload transport of contributary streams has to be credited that the efficiency of these reservoirs was still to be maintained by flushing.

11. Height of Sedimentation (Deposits).

By comparing two reservoirs under otherwise equal conditions but with deposits of different development we find that the quantities flushable with equal volumes of water are greater by further developed deposits because the fall within the channel is greater at the beginning or, with other words: small water volumes can move relative great quantities. But it is to be taken into account that these quantities under circumstances at normal fall of flow will deposit themselves below the weir and are not removable.

Of the properties of the deposits we finally will mention:

12. The Coefficient of Sedimentation.

It has already been said that the effect of the flushing stream in its width is so much better as the deposited sediment is made up of finer particle size. Furthermore this fine masses are lying nearer towards the weir and need only a moderate shearing force for transport. Greater difficulties are encountered by reservoirs at mountain streams with rich bedload transport. Just for such reasons has the by pass

channel at the dam having been constructed in order to take care of the rough bedload and to prevent any difficulties at the flushing of the sediment which deposited within the reservoir.

13. The individual particle form of the deposits.

Schoklitsch in his tests has demonstrated how far the form of the single [illegible] of the sediment whether rounded or flat exercises an influence.

14. Age and Adhesion of Sediment.

Sediment which settles upon the bottom to become a compact deposit of adhesive quality separate their moisture in a higher grade and is naturally more difficult to remove than loose, [illegible] or greatly water holding younger deposits. These deposits often take up no water without a mechanical [illegible]. Another difficulty particular at alpine valleys is the fact that the bedload quickly becomes a mass of substantial adhesion. [illegible] reported that the glacial streams and for [illegible] did sometimes carry a fine bedload of strong binding qualities exceeding even the newly formed banks of sediment. Bedload made up by lime shows only little adhesion and is more favorably for flushing.

[illegible] reported of the flushing at the [illegible] plant that the gravel at several points on the bottom has formed banks about like concrete. The properties of deposits are particularly influencing the fall of [illegible] finally reached by the flushing channel.

B. Means of Increasing the Flushing Effect.

Almost all often proposed especial means of preventing the sedimentation or for elimination of deposits can here be mentioned as recourses for an increase of flushing effect.

First we will investigate:

1. The Flushing at Empty Reservoir.

To point out the artificial produce of a somewhat greater volume of flushing water by a small [illegible] a reservoir above or repeated [illegible] if necessitated by circumstances--further the repeated partial [illegible] and sudden discharge--further a concentration of water volumes upon narrow channels. The latter method was applied at the day storage reservoir of the water power plant [illegible] by constructing guiding walls (Fig. 8) whereby the flushing proceeds in a way that the entire water volume at disposal (after the lowering of the water level) is directed through one channel only whereby the increased velocity of flow carries away the mud between the guiding walls. Such a construction at small reservoirs is only then economically advisable if the heavy

bedload transport would produce a very quick sedimentation (deposit) and if the preservation of the reservoir is of particular importance.

The important sidewise transport of masses up to the flushed channel is often done by hand sometimes by the use of compressed air or water pressure.

8. Flushing at Full Reservoir.

The interruption of operation caused by a natural[33] flushing and the desire of a permanent flushing or to use the drained water for this work leads again and again back to proposals of flushing a filled reservoir under assistance of special measures.

The effect of a flushing outlet in the wall locally limited as it is can be produced at any point in the reservoir if one provides a tube from the discharge in the wall to the respective point.

Gonnet proposes a net of such tubes spreading far upon the bottom of the reservoir[34]. In the side tubes of 1a/ are at many points openings provided through which the water enters rapidly (if all other openings are periodically closed) and is then discharged by the main tube (1.50 m Ø). The instruments for adjustment of inlets reach above the surface of water and can be reached by the help of a boat. Two smaller openings in each inlet cover can be used for freeing (by flushing) the inlet covers from bedload which may have deposited upon them. But much better than this rigid system is the often proposed and constructed method with syphons. Instead to connect the outlet in the wall with the tubes on the bottom the outlet now is connected with a flexible pipe line resting by means of a swimmer upon the surface of the water. The suction nozzle at the end kept at the water surface by a greater swimmer (upon which the vacuum pump also is installed) can be operated at any point of the reservoir. It has the same effect than a suction dredger and a cutting head may be adjusted to the lower end to break up the more compact masses of deposit. Jaatis at the clearing of the dam Djidiouia (Algeria) had good results with this method. He removed 1 hm^3 of deposit within three years.

Al Vagt[35] proposed for a similar method self priming syphons whereby the vacuum pump aggregate is economised.

After all it appears as if this proposal of Vagt is advantageously used at reservoirs where interruption of the operation by natural flushing are possible to be avoided and where the contributory streams carry heavy bedload.

9. Something about the Construction of Flushing Outlets and Operations of Flushings.

Of all the protective methods of sediment removal are those applied at the ancient Spanish Irrigation dams build by the Moors of particular interest. There the protective work to save the reservoirs from becoming useless by

deposits goes on for centuries. The large flushing outlets in the wall are at the waterside closed by a wooden gate the so called "Spanish Gate." Every time when a flushing was set into action (the rule prescribed a flushing after relapse of four years but usually more years went by before respective flushings) the mud had deposited itself to a great height also before the wall (30 to [illegible] m). The approach was made from the flushing gallery (from the airside) then the gate was removed under great risk of life by taking away the supporting beams after soundings of the deposit lying directly against and before the gate whether it was of enough compactness or whether it would immediately break through the freed opening. Then the mass of deposit is loosened with a sort of flat stamper chisel operated from the wall key until the flushing channel is reached. A large funnel forms after a short while and then the upstream widening back to the deposit.

But this method had a set back as each time it could not be judged therefore later a iron sluice had been chosen which was mechanically operated (Huelva Almeria e.t.c.). The enormous measure of this sluice of course allowed only a very slow opening because the mechanism had to be of robust construction in regard to the large outlet and the great water pressure and this consequently caused the loss of great valuable volumes of water before an effectful cross section of a flushing gallery was laid free.

These difficulties are unknown at most dams because the flushing outlets are usually of much smaller measures. But this fact is then perhaps then less effectful for discharging of mud masses.

The author on the basis of his investigations comes to the conclusion that in all cases where a natural flushing (in regard to substantial transport of heavy bedload) is found necessary or allowed a sufficient large flushing outlet should be chosen.

A ground outlet is indispensable for a quick discharge in case of any danger and for emptying at cases of examination or flushing. Since it operates under pressure it can be constructed in such great measures as required for outlets at greater storing heights therefore it would prove very practical to install the flushing discharge at the side of the bottom outlet and so foregoes an operation under pressure.

DREDGING

Dredgings of dam reservoirs are provided in such cases where the building of a by pass is impossible and where flushings are not successful to it for the reason that the reservoir only seldom can be drained or that the present flushing outlets do not comply with the above requests or that the reservoir is too broad for thorough flushings or too steep or finally whether the particles of the deposit are of too coarse size. Mostly used are then dredger bucket chain or better suction dredger operating at moderate water level in the whole area of the dam but at higher water levels only at the fresher deposits in the upper part of the reservoir because dredging of greater depths would prove uneconomical respective impossible. (Greatest dredging depth of suction dredger = [illegible] m.)

damaging pipes in the basement. [illegible]

[illegible]

But this method had a [illegible] as [illegible] it could not be [illegible]

[illegible]

These difficulties are unknown, [illegible] because the flushing outlets are [illegible]

[illegible]

The author on the basis of his investigations comes to the conclusion that [illegible] of heavy outlets is found necessary or at least a constant large flushing outlet should be chosen.

A proper outlet is indispensable for a quick discharge in case of any [illegible] and for carrying of [illegible] of [illegible]. [illegible] it can be constructed in [illegible] outlets at greater starting heights than [illegible] an operation under pressure.

[illegible]

Predictions of [illegible] are [illegible] of a [illegible] is impossible and [illegible] the reason that [illegible] only [illegible]

[illegible]

Whereas by less fluctuating water surface the coarse masses of sediment at the inlet are rather compact and easily to be dredged the delta at stronger fluctuation of the water level is extremely drawn out so that in such a case the bedload further should be trapped in a forebay and later dredged from there.

The disposal of the dredged quantities of course has its difficulties also to use it for its ideal qualities for building purposes is mostly forbidden by the great distances to the site of respective buildings. The other way of disposal by dumping it into the stream again below the dam has also its setbacks in the fact that the stream in consequence of the great draw upon the water does not retain enough scouring force to transport the deposits.

[illegible][illegible] proposed to transport the dredged deposits from the storing lake in load-clouds through channels to the shipping places along the lower stream section. On the other hand it is to be said that the dredged masses represent an ideal material for revetments at shallow shore zones within the reservoir because this shallow area in view of its cost price contributes only a small volume to the reservoir. In hot countries this shallow areas alternately lying dry or forming swamps are regular breeding places of fever.

Dredging is sisyphus work because the dredged space fills up the quicker the greater the volume is above the $I_{[illegible]}$ which is created by dredging because the sedimentation shows a increase proportionally.

ELEVATION OF THE DAM

If for economical or other reasons the storing space of a reservoir can not be freed from the deposits then the heightening of the dam will provide valuable volume of great proportion and simultaneously warrant the retention of the dam site. So for instance has the [illegible] dam (Tunis) whose original storing volume of 11 hm³ after 25 years became reduced down to 5% by an elevation of 7 m been brought to 27 hm³ storing capacity.

The capacity of the [illegible] dam had diminished from [illegible] but the elevation of its dam increased it from 5 hm³ to 100 hm³.

The [illegible] lake of the city [illegible] completed in 1892 and rendered useless within 12 years (table 1) remained with its new reservoir (= 200,000 m³; this has been accomplished in 1908 by an elevation of the dam wall for 5.35 m. The dam serving as a day reservoir for the power plant [illegible][illegible]. The city of [illegible] now dredges about 70,000 to 80,000 m³ gravel sand per year from the [illegible] dam (corresponding to the yearly transport of heavy bedload in the basin) so that with these dredgings for the new reservoir probably a state of equilibrium has established itself.

The dam [illegible] water [illegible] of the city of [illegible], [illegible][illegible] with

[illegible] original capacity of 1.[illegible] hm^3 has been [illegible] down to [illegible] 0.[illegible] hm^3 of the 1.95 hm^3 at the beginning [illegible] years ago. It was possible to keep the volume at about [illegible] hm^3 [illegible] during the years from [illegible] by the use of a suction dredger. Then a small reservoir of similar size was built directly above this small reservoir [illegible] was brought on by an elevation of the [illegible] dam wall in [illegible], so that difficulties have not to be expected for [illegible] (table [illegible]). Fig. [illegible] shows the elevation of the wall of the reservoir of [illegible].

The static conditions changed by the deposits are always to be observed but particularly during dam elevation. [illegible] little about the side pressure of [illegible] but it may be expected that [illegible] the character can be greater but also smaller than the respective pressure of water. On one hand the specific weight increases in following succession: water, muddy water [illegible] and sand in dense [illegible] layers (deposit) but on the other hand the decrease of pressure in consequence of the increasing firmness of thrust has again to be subtracted.

SPACE OF SEDIMENTATION (DEPOSIT)

Sometimes the fact of sedimentation is accepted as [illegible] and the reservoir is designed with a corresponding space as a protection against [illegible] deposits. So the Elephant Butte reservoir on the Rio Grande has been built of much greater proportion as the present water economical demand requires. At Oued-Fodda (Algeria) a 30 hm^3 sedimentation space for [illegible] years had been provided at the new Fuentes [illegible] 3 hm^3 for [illegible] years at [illegible] at the water economical investigations of the storing volume [illegible] hm^3 a space of [illegible] hm^3 had been set aside as a sedimentation room. The space taken up by deposits [illegible] that has been [illegible] more or less over all parts of the reservoir particularly at [illegible] reservoirs. [illegible] economical [illegible] and storing volumes particularly [illegible] of greater height are lost. It follows that by equal sedimentation [illegible] an [illegible] the heavy [illegible] transport of the [illegible] stream is of [illegible] size and therefore deposits mainly at the upper section as if it [illegible] of [illegible] size but mainly fills up the otherwise anyway not usable "dead volume." The heavy deposit is [illegible] the "dead volume" [illegible] by frequent lowering of the water level, because every lowering signifies [illegible] the [illegible] the earlier described "flushing effect at empty reservoir."

CONSIDERATION OF SEDIMENTATION [illegible] AT THE [illegible] OF DAMS

1. Investigation (to be performed)

[illegible] investigations of the sedimentation [illegible] which have to be performed at the [illegible] of dams on streams transporting heavy [illegible] by small [illegible] also at relative less heavy [illegible] transporting streams —

the determination of the heavy bedload freight of a time unit will again and again be the given task. To be determined is: the heavy bedload freight of the untreated stream the portion of heavy bedload freight which [illegible] not come to sedimentation in the [illegible] reservoir (overfall discharge e.t.c.) the quantities [illegible] by artificial means (flushing dredging e.t.c.). It is regrettable that our knowledge of the relative connections are so little with [illegible] the characteristics of the precipitation area—the course of the stream the reservoir to be constructed and the sort of regulations to hinder a sedimentation (forming of deposits) respective to remove these deposits all of which would offer data of the magnitude of deposits. Therefore it becomes necessary to make [illegible] systematical investigations in addition to the mentioned special investigation before the start of reservoir constructions. Systematical observations should be made on stream courses and existing storage reservoirs. The observations concerning the heavy bedload conditions in stream channels relate mainly in the direct determination of the bedload freight by the medium of suitable instruments—the performance of bottom investigations and the drawing of mixture lines (according to [illegible]). As a dependable calibration of the instruments is [illegible] (to bedload and deposit [illegible]) would serve similar extended measurements like those of [illegible][illegible] performed at [illegible] on the [illegible] above a corresponding reservoir and observation of the ratios of sedimentation increase in the reservoir and that is of further importance by a simultaneous measurement of the heavy sediment discharged from the reservoir by operating bottom discharge and overfall with the same instruments (to be calibrated). The storage reservoirs for these purposes should neither be too small nor too large in order to make a measure of the sedimentation increases by the use of small methods but covering the complete space of the storing surface and not only the [illegible] as it should be the case of great lakes.

The further systematical investigations of stream courses performed by the use of these calibrated instruments should [illegible] up possiblest long periods of time and possiblest at a number of succeeding points of the same stream [illegible] in order to obtain also the changes in relation of the changing stream channel characteristics. For a demonstration we propose a heavy bedload freight mountain chain whose elevation signify heavy sediment coefficients [illegible] in the ground plan one direction is to note down as time and the other direction the [illegible] of the longitudinal direction of the stream. A vertical cut into the one or other direction results every time in a valuable line of passage ([illegible]). These passage lines can be substituted in one or the other direction by their own passage lines which [illegible] to [illegible] below proposed method of energy economical investigations combines and [illegible] represents a heavy bedload run passage plan.

The systematical observations should particular [illegible] the relation between the easily obtainable properties of the precipitation area the stream bed and the reservoir so that one has to [illegible] lines at individual cases only a part of the expensive heavy bedload freight measurements of long duration and otherwise help oneself by estimation respective calculation.

The necessary special investigations before the start of the [illegible]

The calculation of the heavy incident result at a time much with some and ought be done given term. It is determined for the heavy dominant fact it of the undamaged survey the section of heavy unrecord scoured a high zone and some in maintenance to the large permeating [illegible] limits a.s.f. the graduation curve is by statistical means (the- ing used the e.s.f.). It is revealed in this manner of the selective connections are as little with an employ the classification of the presumable ... curves of the stream the necessity is to [illegible]

Filling of deposits necessitate to remove these deposits all of which would a few date of the conditions of humidity. Therefore it becomes necessary to use a extra statistical investigation in addition to the continued annual investigation before the start of the yearly operation. Systematical observations should be made on storing sources and [illegible] reservoirs. For the practical [illegible] of the heavy material conditions in stream channels [illegible] of the [illegible] of the sediment [illegible] by the [illegible] and the [illegible] of [illegible] according to [illegible]. As a [illegible] of the [illegible] in [illegible] and [illegible] measurements like those of [illegible] performed at [illegible] [illegible] observation of the point of sedimentation increase in the [illegible] and also as of further [illegible] for a [illegible] assessment of the [illegible] sediment discharged from the reservoir by scouring bottom discharge and overfall with the [illegible] in a [illegible]. The [illegible] reservoir for these purposes should neither be too small nor too large in order to [illegible] of the sedimentation increase in the use of small [illegible] but covering the complete space of the storage surface and not only the [illegible] as it should be the case of [illegible].

The further systematical investigations of [illegible] performed by the use of these [illegible] instruments should [illegible] [illegible] [illegible] and [illegible] of a number of [illegible] [illegible] the same [illegible] section in order to [illegible] the [illegible] of the [illegible] [illegible]. For a [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] in the [illegible] and [illegible] to [illegible] [illegible] of the [illegible] [illegible] of two [illegible]. A [illegible] [illegible] or other [illegible] results every time in a [illegible] line of [illegible] [illegible]. These [illegible] lines [illegible] in one or the other [illegible] by their own [illegible] lines [illegible] [illegible] [illegible] method of [illegible] [illegible] investigations [illegible] [illegible] a [illegible] [illegible] [illegible] line.

The [illegible] [illegible] should [illegible] [illegible] the [illegible] between the [illegible] [illegible] properties of the [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] of long [illegible] and [illegible] [illegible] by [illegible] [illegible] [illegible].

The necessary [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible].

construction should naturally measure [illegible] such similar cases of disagreeable experiences of the upper heavy bedload conditions of the stream course and should be studied very intensively. They also should cover a possibly long period of time therefore again one should choose such stream sections for the performance of systematical observations at which the construction of the dam is to be realized and where special investigations are to be made.

Today in the practice we come more and more to the aspect that in a given case as here to do the preparatory work in a most [illegible] way. We will mention the observations since [illegible] at the [illegible] (projected dam of [illegible]) the observations of years at the [illegible] near [illegible] and the careful measurements on the [illegible] near [illegible] and others.

The systematical performance of investigations of storing reservoirs should include:

a. The discovery of heavy material (which above and below [very important!]) in connection with:

b. definition of the sedimentation progress by profile measurements (also before the start of construction) cross and longitudinal sections determination of mass (Massenaufnahmen).

c. Analyses of sieving of the transported heavy material above the reservoir the depositing at diverse points and the heavy material below the dam; plotting of mixture lines.

d. experiences in constructions of revetments and for flushing dredging a.s.o.

e. relative comparisons between weight and deposit volume of the heavy material.

f. In connection with the upper observations permanent water gaugings have to be made. Of course it would be very welcome if all observations and experiences particularly those disagreeable ones were published.

The following instances will show the method of such measurements:

Detailed measurements of the first months of each year are made at the [illegible] at the time of [illegible] upon the [illegible] experiences of the first years and substantial sections above the dam as well as below the [illegible] are included. One measured in [illegible] km stream length (of [illegible] km above and [illegible] km below the dam [illegible] km above the end of the weir and [illegible] km below discharge) all together [illegible] cross sections corresponding to an average interval of [illegible] m between each other[illegible]. At the [illegible] measurements of cross sections of [illegible] intervals are obtained every year by the [illegible] of the state.

[illegible]

[illegible]

The [illegible] should include:

1. [illegible]

2. [illegible]

3. [illegible]

4. [illegible]

5. [illegible] between weight and [illegible] volume of the [illegible].

11. In connection with the upper observations [illegible] water [illegible]. If [illegible] it would be very [illegible] particularly [illegible] were [illegible].

The following features will show the method of each measurement.

[illegible]

In [illegible] an investigation was made to obtain the substantial facts about the deposits and the nature of their particles by drillings and dredging at [illegible] localities[illegible]. Of great advantages proved a sounding from a firm bank of ice as is done every year at the [illegible] dam. Of course mostly one will have to do the sounding from a boat which is adjusted from two points of a triangulation net laid around the reservoir for determination of the point of measure.

2. Conversion of heavy material to space (Volume) of deposit.

At the conversion of the heavy material (weight) in the sedimentation space is done [illegible] following [illegible] (Fig.[illegible])

If: G = weight of deposit t/m³
g_s = weight of heavy material in 1 m³ deposits t/m³
γ_s = specific weight of heavy material t/m³
γ_o = specific weight of water t/m³
p = volume of voids of heavy material (filled with water) then is for deposits (saturated with water):

$$G = g_s + w = \gamma_s (1 - p) + \gamma_o p = \gamma_s - p(\gamma_s - \gamma_o)$$

Therefore the weight of deposits is obtained from the specific weight of heavy material and the water percentage as it presented in figure [illegible]. If both values are known then the weight of the dry material g_s in 1 m³ deposit can be defined and the volume (space) of sediment V can then be determined by plain computation from [illegible] heavy material to:

$$V = \frac{G}{g_s}$$

In order to find g_s it is not difficult to define γ_s but the value p will appear in diverse qualities even within the same reservoir because the water filled volume of voids within the deposits is dependent from the (mean) particle combination of the heavy material from the weight of mud and water lying upon a fixed point of deposit from the age of the deposit and from the manner of sedimentation process whether in quiet or turbulent water[illegible] further whether any potential possibilities exist for drying or shrinking.

It is for these directions and to a part for the reason that not always a clear distinction between G and g_s is made that a great fluctuation of the values g_s in literature is caused. Several characteristic values are collected in table 2.

In regard to mud and sand deposits of great compactness a conversion coefficient of g_s = 1.[illegible] to 1.[illegible] has to be accepted according to table 2 but at rougher deposits filled with fine material values g_s

[illegible] conditions". If great accuracy is required a result from a fine kind of [illegible] the [illegible]. Of course one will have to [illegible] from a point which is adjusted from two points of a triangulation net [illegible] necessary for determination of the point of [illegible].

4. Determination of heavy material in [illegible] deposits

At the conversion of the heavy material fraction in the sedimentation zone is done according to following stipulation (fig. [illegible]):

If: G = weight of deposits t/m³

G_s = weight of heavy material in 1m³ deposits t/m³

γ_s = specific weight of heavy material t/m³

γ_q = specific weight of quartz t/m³

n = volume of voids [illegible]

is for deposits (saturated with water):

$$G = G_s + n \cdot \gamma_w + (1 - n) \gamma_q [illegible]$$

Therefore the weight of deposits is [illegible] from the specific weight of heavy material and the [illegible] as is represented in figure [illegible]. If [illegible] the weight of the dry [illegible] G_s is [illegible] deposit [illegible] and the volume [illegible] of sediment V [illegible] heavy material are

$$V = \frac{G}{G_s}$$

In order to [illegible] the value [illegible] appear [illegible] water filled volume of voids which [illegible] from the [illegible] of the heavy material from the weight [illegible] from a fixed point of deposit from the [illegible] of the deposit and from the [illegible] of sedimentation [illegible] which [illegible].

It is [illegible] always a clear distinction between G and G_s is made that a great [illegible] of the values G_s in literature is caused. [illegible] values are collected in table 2.

In [illegible] of great [illegible] coefficient of γ_s = 1.[illegible] to 1.80 [illegible] table [illegible] deposits filled with [illegible] values [illegible]

to 2.00 and over have to be applied. But for the fact that mostly great portions of deposits particular of newer ones and such which seldom lie dry during operation show a much lower grade of density one will have to choose the mean conversion number g_o somewhat smaller correspondingly to the greatest state of density of the respective material.

8. Generalities about the Project.

If by observations the conditions of heavy material of the unlocked stream have been characterized as difficult then a careful investigation has to be made how the proportions and the operation of the reservoir are influencing the deposits (chapter IV) and whether and which peculiar means (chapter VI) should be applied to hinder resp. to lessen the sedimentation.

The yearly expenses for the maintenance of at least a certain space of the reservoir free from deposits consist of the capital service of the singular and great costs (of construction of provisions protective works by pass channels a.s.f.) the running operation expenses (including such for repairs flushings dredgings a.s.f.) to which are to be added the loss of income caused by interruption of operation (for instance during periods of flushings) are to be compared with the yearly costs of a projected new reservoir (including discharge lines power works a.s.f.). These economical considerations under circumstances may lead to the conclusion that an otherwise favorable dam site is not chosen for a dam construction.

The extremely high maintenance costs at existing important storing reservoirs are often justified (seeing during a storage) whereas many times particularly at large reservoirs one has to calculate with such periods of sedimentation much greater than the highest economical depreciation one requires.

But even as it is for the reason of political economy that in such a case it seems essential not to consider the high costs of the project only but to think of the fact that a favorable dam site represents a common public property alike other natural resources.

I wish not to fail in thanking Professor [illegible] for the helpful assistance in my work and allow me to mention here a number of persons departments corporations and communities which by submitting to the called circulars contributed a great part to my work.

1. That are values of annual floods. Greatest measured values at catastrophical floods; at the Rhine above [illegible] (lake of Constance) according to [illegible] 58 s/l at the [illegible] according to [illegible] 100 s/l at the [illegible] 100 s/l at the [illegible] "the saddest river of [illegible]" up to 400 s/l (?)

2. [illegible]schaff "Die [illegible]bewegung in Flüssen [illegible]" Dissertation Berlin [illegible].

3. In a newer expression (like the proposal of Schoklitsch) / is a function of bedload quality whereas the exponent of I is not [illegible] Wz.u.Fw1934[illegible].

4. Only for the part of the catchment area which is not occupied by the lake.

5. Accordingly to informations by General Director [illegible].

6. Principles of Irrigation Engineering. London [illegible].

7. [illegible] Das Elektrizitätswerk [illegible] Wa. 1929H[illegible].

8. [illegible] Le charriage des alluvions dans certains cours d'eau de la Suisse. Ann. Schweiz. Landeshydrogr. [illegible] Bern [illegible].

9. [illegible]s Landeskunde der Unterwaldischen Alpen Stuttgart [illegible].

10. [illegible] Financial limitations in the employment of forest cover in protecting reservoirs Bulletin 1900. Department of Agriculture Wash. [illegible].

11. [illegible] "Der Po" Wa. [illegible].

12. Ludin "Die Wasserkräfte" Berlin 1913.

13. Accordingly to information of the Direction of the Schweizer [illegible] Bern.

14. Schoklitsch "[illegible] in Flüssen und an [illegible]" [illegible].

15. Willcocks Egyptian Irrigation. London 1913.

16. [illegible] Paris [illegible].

17. [illegible] Wz.u.Fw. 1933 H. 1ff.

18. [illegible] 1901.

19. Accordingly to information by Professor van [illegible] "Dienst voor Water Kracht en Elektriciteit Bandoeng Java.

80. That is flushing without special reservoirs.

81. [illegible] "Cours des barrages" Paris [illegible] edition.

82. Vogt "[illegible] transport durch [illegible]" [illegible] u. [illegible] [illegible] S [illegible].

83. [illegible] "Der [illegible] in [illegible] und [illegible] auf ein [illegible]. [illegible] 19[illegible].

84. Collet "Les Lacs" Paris 1925.

85. According to informations of the [illegible] of the City of Baltimore.

86. [illegible] investigations of heavy material and bedload transport of the Inn near Kirchbichl (Tyrol) [illegible]

87. [illegible]: The influence of a weir upon a bedload transporting stream. Bautechnik 1931 Heft 53 S 748.

88. [illegible] "The morphological transformation of bedload transporting streams in connection with great waterpower utilization. Wkr. Jahrbuch 1930/31.

89. [illegible], [illegible] für [illegible]: [illegible] der [illegible] in natürlichen Gewässern. [illegible] S [illegible]. Determination of the bedload transport in natural waters.